Development of Ecological Indicator Guilds for Land Management: Characterizing Ecosystem Metrics Along a Disturbance Gradient

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Abstract

Nine research sites were selected in Sand Hills physiography of Fort Benning Georgia that represented a disturbance gradient of military training activities, three sites each in High, Medium, and Low disturbance classes. High sites have a high level of current mechanized infantry training activities. Medium sites had a past history of military training activities, but are only lightly used at present. Low sites have not experienced military training activities. Six Ecological Indicator Systems (EIs) were separately analyzed with discriminant analysis to extract six suites of environmental variables that best characterized this disturbance gradient. These groups were called Ecological Indicator Guilds, because of their respective functional and defining response to the disturbance gradient. The High sites were readily separated from the Low and Medium sites by DF1 and the Low and Medium sites were separated by DF2 in three of the EIs: General Ground Cover, Soil Chemistry, and the Ant Community. The Microbial Community EI was only able to separate the High from the Low and Medium sites on DF1. Only the General Habitat and Woody Ground Community EIs were able to effectively separate the three disturbance classes with only DF1 as the discriminator. Although these results are preliminary with additional analyses planned, the General Habitat Guild consisting of only two variables, A-Horizon Soil Depth and Soil Compaction, and appears to represent a robust Indicator Guild for characterizing the disturbance gradient.

Introduction

Military training and testing lands must be efficiently and cost effectively monitored to assess conditions and trends in natural resources relevant to training sustainability, ecosystem maintenance, and the timing and success of restoration efforts. Ecological Indicator metrics represent important land management tools for tracking ecological changes and providing early-warning detection of threshold impacts relevant to training/testing missions. The objective of this research is to develop Ecological Indicators based on ecosystem relevant criteria, multi-scale performance, and stress-response criteria, for the purpose of monitoring ecological changes directly relevant to biological viability, long-term productivity, and ecological sustainability of military training and testing lands.

Ecosystems consist of soil, primary producers (plants), and consumers (animals) in a given physiographic-continental setting, which includes geology and climate. Soils are functionally characterized by biological (microbes and animals), chemical, and physical attributes. On the basis of the experience of our research team and the literature, we selected seven Ecological Indicator Systems (EIs) that represented all three ecosystem components: **1) Habitat Characterization** (physiognomy, floristics, soil physical properties), **2) Soil Chemistry**, 3) Nutrient Flux and Leakage, **4) Microbial Communities**, **5) Invertebrate Communities**, 6) Plant Physiology, including Developmental Instability, 7) Plant Community Spatial Interactions. Some of these major indicator system categories contain multiple EI subsystems. The EIs that are capitalized will be specifically evaluated in this report. Our working hypothesis was to statistically characterize the response of these EIs along a military training disturbance gradient.

Suites of environmental variables within EIs that analytically portray the disturbance gradient were called Ecological Indicator Guilds. Guilds have a long history of use for classifying biological organisms with similar ecological function or exploitation of resources (Root 1973, Holmes et al. 1979). However, guilds have also been used in a broader context to classify ecosystem use by amphibians (Krzysik 1998), forest cover and age classes (DeGraaf and Chadwick 1984), and for environmental management, assessment, and monitoring (Järvinen and Väisänen 1979, Hawkings and MacMahon 1989). In our research context, guilds will represent suites of environmental variables or species groups explicitly characterizing a disturbance gradient.

Methods

Study Sites

Nine research sites were selected in pine – scrub oak Sand Hills physiography of the uppermost Southeastern Coastal Plain at Fort Benning, Georgia. Three sites each were classified into HIGH, MEDIUM, and LOW disturbance classes. *High* sites are characterized by current extensive mechanized infantry training activities employing tracked tactical vehicles. *Medium* sites experienced past military training activities, but are currently only used periodically by foot soldiers. *Low* sites have never been subjected to military training activities, and are currently protected

Field Methods

Habitat variables were collected along four perpendicular transects centered on the site using a trowel and metric ruler (A-Horizon Soil Depth), Lang Penetrometer (Soil compaction), concave spherical densiometer (Canopy Cover), vane shear tester (Soil Sheer Strength), DBH tape (tree diameter), Cruz-All angle gauge (Basal Area). Ground cover variables were collected along six transects in the center of the site using 13 randomly located 0.59 m^2 round quadrats on each transect.

Soil chemistry and microbial analyses were performed in the laboratory from six samples at each site, each sample consisting of a composite of six soil samples taken to a depth of 15 cm. Soil chemistry was conducted using standard methods, and the microbial community analyses were performed with the BioLog procedure (Zak et al. 1994, Sobek and Zak 2002).

The ground/litter ant community was sampled with pit-fall traps. Each trap consisted of a plastic 9 oz cup buried flush with the soil, adding 10 ml of propylene glycol as a preservative. Four to six clusters of four or five traps at each cluster, depending on year, were used at each of the nine sites in 2000 and 2002. Only six sites were sampled in 2001, two in each disturbance class. The collected ants were identified in the laboratory using available ant keys.

Statistical Methods

Discriminant analysis (DA) was performed on the six Ecological Indicator Systems to extract Ecological Indicator Guilds. DA weights the predictor variables (e.g., habitat variables) such that their linear combinations maximally distinguish (discriminate) among two or more predetermined groups or classes (Krzysik 1987). The well-known F-ratio tests the criterion for measuring class differences, sums of squares between groups versus sums of squares within groups: $F = SS_b/SS_w$. By rewriting sums of squares terms in the form of vectors of linear combinations of predictor variables, the matrix form reduces to:

$$\mathbf{v'Bv} / \mathbf{v'Wv} = \lambda$$

λ represents the discriminating criterion, and the discriminant problem reduces to extracting the set of weights, or coefficients, that maximizes λ. In other words, covariance structure among groups is maximized, while minimizing within groups covariance. Discriminant Function 1 (DF1) maximally distinguishes the groups, DF2 represents the second best discriminant function, and so on. The number of derived discriminant functions is equal to one less than the number of groups in the analysis. DA has several desirable properties. When sample sites lie along a disturbance gradient, DA identifies the variables that best define the gradient. Because the method is sensitive to data matrix singularity, variables that possess high colinearity with other variables are omitted from the analysis (Tabachnick and Fidell 2001). Both direct (all variables entered simultaneously) and step-wise methods were used in the DA. Step-wise methods have been severely criticized (Green 1979), but their use in conjunction with direct analysis assists in assessing the robustness of analyses. In all the analyses presented here, both methods yielded identical patterns. The results of direct analyses were used to derive the discriminant scores that were plotted in the figures.

Results

Six Ecological Indicator Guilds were constructed from six Ecological Indicator Systems using discriminant analysis (DA).

DA Ecological Indicator System → Ecological Indicator Guild

General Habitat (11 variables)

Horizon Soil Depth	Tree Density	A-Horizon Soil Depth
Soil Compaction	Tree Diameter (mean)	Soil Compaction
Soil Shear Strength	Canopy Cover	
Basal Area	Tree Size Distribution (densities of 4 Basal Area classes)	

General Habitat Guild (Figure 1)

General Ground Cover (7 variables)

Bare Ground	Legume Cover	
Litter	Woody Cover	
Forb Cover	Woody Species Richness	
Grass Cover		

General Ground Guild (Figs 2 & 3)

Bare Ground	
Woody Species Richness	
Forbs	
Grass	

Woody Ground Cover Community

34 Woody Species Ground Cover

Woody Ground Guild

Rubus cuneifolius *Quercus margarett*
Rubus flagellaris *Quercus incana*
Prunus angustifolia

Soil Chemistry (6 variables)

Soil Organic Carbon	Nitrate	
Microbial Carbon Biomass	Ammonium	
Moisture	pH	

Soil Chemistry Guild (Figure 4)

Soil Organic Carbon	Nitrate	
Microbial Carbon Biomass	pH	

Microbial Community (4 variables)

Fungal Functional Diversity

Fungal Total Activity

Bacteria Functional Diversity

Bacteria Total Activity

Microbial Guild

May

Bacteria Functional Diversity

Fungal Total Activity

November

Bacteria Total Activity

Fungal Total Activity

Ant Community

27 Species of Ants (abundance)

Ant Guild (Figures 5 and 6)

9 Species of Ants (Table 1)

General Habitat Ecological Indicator System

Three Habitat Ecological Indicator Subsystems were effective in characterizing the disturbance gradient in discriminant space. A fourth subsystem, "Tree Community" was not as effective, indicating that the tree community has either not responded to, or has had insufficient time to respond to the environmental conditions produced by military training activities.

A-Horizon Soil Depth and Soil Compaction (General Habitat Guild) were the most important habitat variables to discriminate among the three disturbance classes (Figure 1). Note how symmetrical the mean discriminant scores are in DF1 space: Low sites = +2, High sites = -2, while Medium sites = 0. This was a remarkable and significant result. The General Ground Cover Guild required both Discriminant Functions to separate sites in the disturbance gradient. Bare Ground and Woody Species Richness separated the High site from less disturbed sites in DF1 (Figure 2), and DF2 separated the Low and Medium sites on the

Figure 1. General Habitat Guild

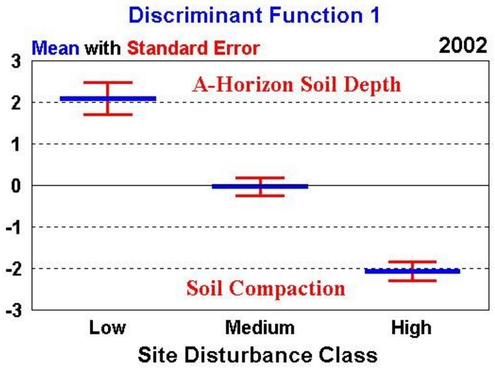


Figure 2. General Ground Cover Guild

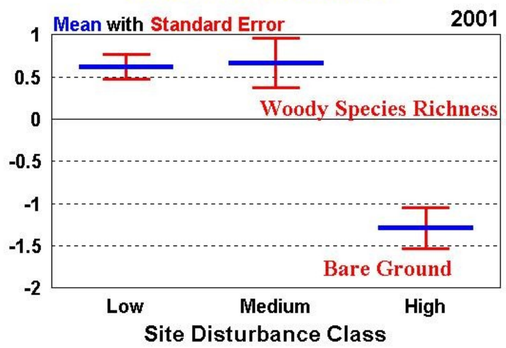


Figure 3. General Ground Cover Guild

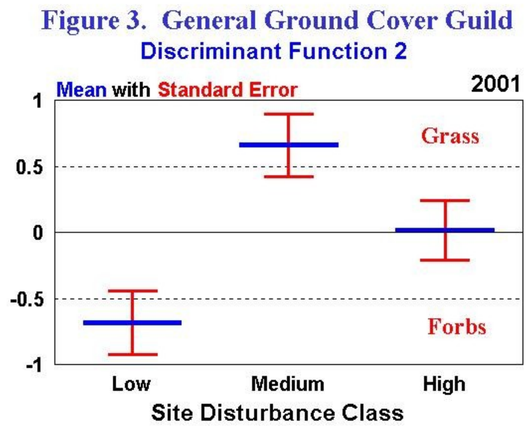
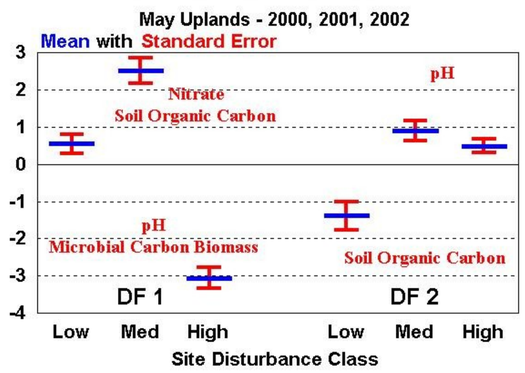


Figure 4. Soil Chemistry Guild



Soil Chemistry Ecological Indicator System

Four of the six variables: Soil Organic Carbon, Microbial Carbon Biomass, Nitrate, and pH were important in classifying the sites in the disturbance gradient (Figure 4). DF1 separated High from the less disturbed sites, while DF2 separated Low from Medium sites. The discriminant analysis for both May and November data produced very similar results, indicating that there were no seasonal effects.

Microbial Community Ecological Indicator System

Three of the four Microbial variables were effective in separating the sites in the disturbance gradient Bacterial Functional Diversity and Total Activity, and Fungal Total Activity. Interestingly, the specific microbial variables and their respective contributions to Discriminant Functions were seasonally dependent, unlike the Soil Chemistry results.

Ant Community Ecological Indicator System

Twenty-seven ant species were collected over the three years of pit-fall trap sampling. Discriminant analysis on the entire data set identified nine species that were effective in discriminating the research sites in the disturbance gradient. DF1 separated the High from the less disturbed sites in all three years (Figure 5), while DF2 separated Low from Medium sites for all three years (Figure 6). Discriminant analyses conducted separately for

Figure 5. Ant Guild (see Figure 7)

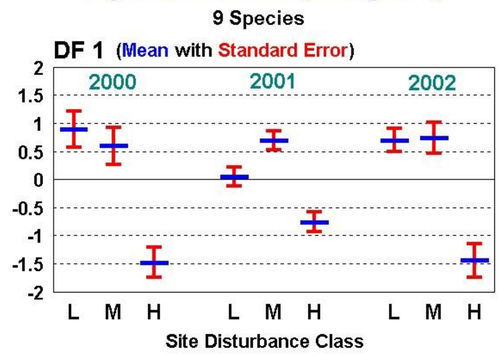
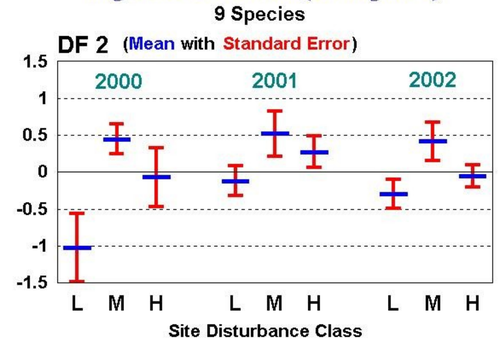


Figure 6. Ant Guild (see Figure 7)



The distribution of ant species abundances among the three site disturbance classes and how they are related to the two Discriminant Functions are shown in Figure 7. Note that the ordinate in this figure is a log scale. Ant species codes and abundances are provided in Table 1. *Dorymyrmex pyramicus* and four species (*Aphaenogaster floridana, Paratrechina parvula, Pheidole sp., Camponotus castaneus*) closely associated with less disturbed sites effectively separated the High from the less disturbed sites along DF1. DF2 separated Medium from Low sites on the basis of three species (*Paratrechina parvula, Forelius pruinosus, Crematogaster minutissima*) more associated with Medium sites and two species (*Aphaenogaster ashmeadi, Brachymyrmex depilis*) more associated with Low sites. Although from Figure 7 it appears that there is not a great deal of difference in species abundance patterns between Low and Medium sites for DF2, it is important to recall that each discriminant function represents a uniquely weighted combination of all 27 taxa, and the species represented in the figure are only those species that possess the highest correlations with the discriminant function of discussion. *Dorymyrmex pyramicus* comprised 96.7 percent of all individuals in the Ant Guild (Table 1). It was of interest to see how the dominance of this species effected discriminant analysis results. Discriminant analysis was performed on the Ant Guild with this species absent from the analysis, and the identical pattern was retained (Figure 8). Apparently, the removal of the dominant species merely reinforced the

Figure 7. Ant Indicator Guild Species

2000, 2001, 2002

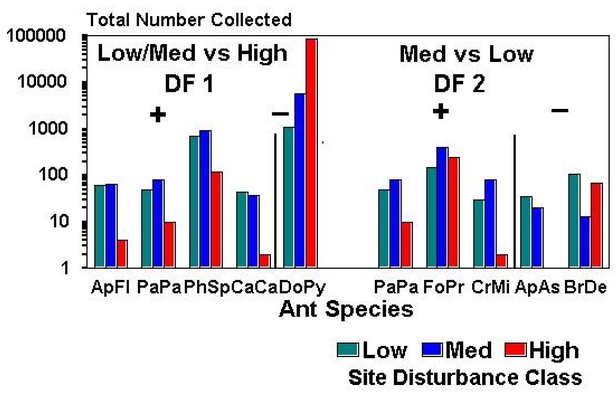
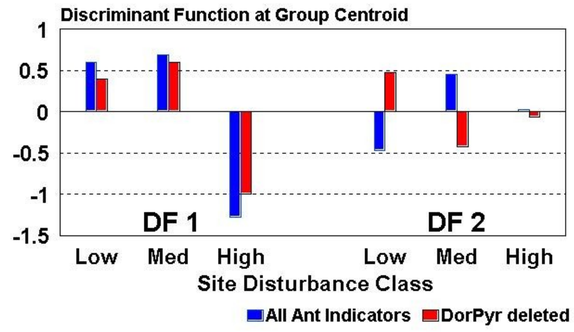


Figure 8. Discriminant Analysis of Ant Community with and without *Dorymyrmex pyramicus*

2000, 2001, 2002



Discussion

A-Horizon Soil Depth and Soil Compaction (General Habitat Guild) were analytically identified as important Ecological Indicators for characterizing a military disturbance gradient, based on the symmetrical distribution of site disturbance classes and the need for only a single discriminant function (Figure 1). The Woody Ground Cover Guild also possessed excellent discriminating power, but requires additional verification with 2002 data. High disturbance sites were readily separated from the Low and Medium sites which were similar. Three guilds accomplished this with DF1: General Ground Cover, Soil Chemistry, and the Ant Community, but requiring DF2 to separate Low from Medium sites. The Microbial Guild was only able to separate the High sites from the less disturbed sites. The Ant Guild (9 species) shows a great deal of promise as an indicator of disturbance gradients, because of the reliable and consistent results obtained in each of the three years. The Ant Community was an effective discriminator of the disturbance gradient even after the numerically dominant *Dorymyrmex pyramicus* (representing 89.7 percent of all ants collected, 96.7 percent of the Ant Guild) was removed from the analysis. The other eight species represented 3.1 percent of collected ants. The remaining ants were the imported fire ant (5.7 percent) and 17 uncommon or miscellaneous species (1.6 percent).

Table 1.

Code	Species	Number	Percent
DoPy	Dorymyrmex pyramicus	94654	96.70
PhSp	Pheidole sp.	1713	1.750
FoPr	Forelius pruinosus	812	0.8295
BrDe	Brachymyrmex depilis	187	0.1910
PaPa	Paratrechina parvula	142	0.1415

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Literature Cited

DeGraaf, R.M., and N.L. Chadwick. 1984. Habitat classification: A comparison using avian species and guilds. Environmental Management 8:511-518.

Green, R.H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. John Wiley, New York.

Hawkins, C.P., and J.A. MacMahon. 1989. Guilds: The multiple meanings of a concept. Annual Review of Entomology 34:423-451.

Holmes, R.T., R.E. Bonney, Jr., S.W. Pacala. 1979. Guild structure of the Hubbard Brook bird community: A multivariate approach. Ecology 60:512-520.

Järvinen, O., and R.A. Väisänen. 1979. Changes in bird populations as criteria of environmental changes. Holarctic Ecology 2:75-80.

Krzysik, A.J. 1987. Environmental gradient analysis, ordination, and classification in environmental impact assessments. USACERL Technical Report N-87/19. Champaign, IL.

Krzysik, A.J. 1998. Amphibians, ecosystems, and landscapes. Pages 31-41 *in* Status and Conservation of Midwestern Amphibians, M.J. Lannoo, ed. University of Iowa Press, Iowa City.

Root, R.B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: The fauna of collards (*Brassica oleracea*). Ecological Monographs 43:95-124.

Sobek, E., and J.C. Zak. 2002. Submitted. The Soil FungiLog Procedure: Method and analytical approaches towards understanding fungal functional diversity. Mycologia.

Tabachnick, B.G., and L.S. Fidell. 2001. Using Multivariate Statistics, 4th ed. Allyn and Bacon, Boston.

Zak, J.C. Willig, M., D. Moorhead, and H. Wildman. 1994. Functional diversity of microbial communities: A quantitative approach. Soil Biology and Biochemistry 26:1101-1108.